NASA-CR-197424

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This is a final report for NASA Grant NAG5-1913 (SwRI Project No. 15-5301).

In our previous report, we noted that we had successfully completed all of IUE observations that were proposed, and that we have reported our results at the 1993 *Lunar and Planetary Science Conference*. In the present reporting period, Dr. Na and Dr. Stern have completed the data reduction and analysis of the data, and presented these results from Venus SO_2 observations at the 1993 *Meeting of AAS Division of Planetary Science*; we are now preparing a paper for publication in *Icarus*.

There were 3 observing programs under NASA Grant NAG5-1913; they are NSOSS, VEOEB, and PCOEB. These programs are described below.

1. **NSOSS:** Comparative UV studies.

The scientific objectives for the IUE observation program NSOSS was to:

- Make the first ever UV observations of i) a near-earth asteroid, 4179 Toutatis, and ii) an irregular satellite of Jupiter, Himalia, and iii) the Saturnian satellite Hyperion.
- Obtain the first radially-dependent information on the UV color of Saturn's rings.
- Gather the never-before obtained, uncontaminated UV spectra of Iapetus's bright and dark hemispheres.
- Obtain a spectrum of Titania to initiate the comparative study of UV photometric properties in Uranian system.

Toutatis

The first ever UV spectra of Near Earth Asteroid 4179 Toutatis were obtained on 9-10 December 1992. The images have exposure times ranging from 90 minutes to 6 hours. We have reported initial results of our observation of Toutatis at the 1993 *Asteroids, Comets and Meteors* meeting. Dr. Festou is completing the final analysis of the data for publication.

Iapetus

One of the most interesting and long-standing problems in the study of the Saturnian satellites is the nature of Iapetus's bimodal surface. In order to understand the origin and nature of the dark material on Iapetus is to make observations that separate the two nearly-hemispheric terrain units. Previous IUE observations of Iapetus have been made at central meridian longitudes of 154-207° and 312-338°. Such observations confuse or mix the characteristics of dark and bright terrain because the central meridians of the two units are at 90 and 270°.

(NASA-CR-197424) IUE OBSERVING PROGRAMS: NSOSS, VEOEB, AND PCOEB Final Report (Southwest Research Inst.) 18 p

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We separated the two hemisphere of Iapetus by making observations during eastern and western elongations of Iapetus which occur about 40 days apart. Two spectra of the bright hemisphere were obtained on 2 November 1992. One long exposure of the dark side of Iapetus was also obtained on 10 December 1992. We compared the UV albedos of Iapetus's dark and bright sides, and found that there are no clear slope to the ratio. We also compared the dark side UV albedo to that of several asteroids. Figures in the appendix show the albedo of the dark side of Iapetus and that of 11 asteroids of various types obtained by IUE over last 10 years. As seen in the figures, the UV albedo is quite similar among different types of asteroids, and the dark side of Iapetus has similar spectral characteristics with all the asteroids with the possible exception of 16 Psyche. Our analyses indicate that Iapetus dark side is consistent with being exogenic in origin, and the dark material may have been created by collisions between Iapetus and asteroids as was suggested by Buratti et al. (1993). We plan to present our results at the AAS meeting in 1994.

Titania

Titania is the brightest of the Uranian satellites, and its albedo is intermediate between Ariel and Miranda (the bright two) and Umbriel and Oberon (the darkest two). We have observed Oberon with IUE in 1989, and this observation of Titania allows us to compare its UV spectral shape and slope to Oberon's. We observed Titania with LWP on 5 October 1992, and obtained one image with exposure time totaling 640 minutes. Our analysis indicate that the signal from Titania was not strong enough to overcome the background radiation of IUE, so this observation was not scientifically useful.

Himalia

Himalia is the largest of the irregular satellites of Jupiter, with a radius of 90±10 km, and an albedo near 4%. Himalia's visible albedo and color suggest it is somewhat similar to C-type asteroids. We have obtained a single, rotationally averaged LWP spectrum of Himalia on 23 February 1993. The total exposure time was 900 minutes. As was the case with Titania, the signal from Himalia was contaminated with the scattered light from LWP. There was not enough useful information in the spectra to continue the analysis further.

Hyperion

Hyperion is the largest irregularly shaped satellite of Saturn, and has highly elongated shape which suggest that it may have suffered a near-catastrophic collision.

2. **VEOEB:** Venus SO_2

SO_2 is an important indicator of key processes in the Venus atmosphere and perhaps Venus surface. Based on past Pioneer Venus and IUE observations, significant SO_2 variations have been interpreted as indicating that the long term atmospheric SO_2 abundance may be related to large, episodic injections from the surface or interior of Venus. If episodic events occur, then continuing observations of SO_2 in the Venus atmosphere play a vital role in our understanding of Venus' current and past geologic evolution.

There were two opportunities in 1993 to observe Venus with IUE. We obtained a total of 10 LWP exposures of Venus in January of 1993, and obtained additional 12 LWP images in June 1993. We also have reported the results from the IUE observations at the 1993 *AAS Division of Planetary Science* meeting (Na, Barker, Stern 1993). The important finding we have reached is that the January 1993 IUE observations indicate that the decline in Venus SO_2 abundance has stopped and seems to have reached the steady state. With more IUE observations of Venus made in June 1993, we have started a project to compare the recent IUE results the ground-based measurements made on the same dates. Our results are presented in the appendix, and will be submitted for publications in *Icarus*.

3. **PCOEB:** Pluto-Charon system

Based on previous IUE spectra of Pluto-Charon system, Stern et al. (1991) have presented an evidence for a variable UV light curve for the system. The UV albedo of Pluto-Charon system decreases substantially between 0.45 and 0.7 rotational phase which is in contrast to the visible light curve which reaches a maximum near 0.65 phase. Our primary objective is to complete the coverage of Pluto-Charon system UV light curve, since only ~26% of the light curve has been observed. A complete, uniformly sampled UV light curve will allow us to analyze the following questions about the surface properties of Pluto and Charon system.

- Does anti-correlation of the UV and visible light curves exist over the entire rotational light curve or just around the hypothesized bright spot at visible light curve maximum?

- Does the contrast (or amplitude) or the light curve increase in the UV as it is for Triton's UV light curve?

- What is the nature and spatial distribution of the substance on the surface of Pluto-Charon system that causes the slope of the reflectance to change in the 3000-3200 Å region?

Our planned observations of Pluto-Charon system were scheduled for the first week of April 1993. However, GSFC postponed our observations to make observations of the Supernova 1993J. The observation Pluto is now scheduled to take place on 4-8 April 1994, and we hope to fill in the UV light curve of the Pluto-Charon system at that time.

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Na, C.Y., Barker, E.S. and S.A. Stern, 1993. *BAAS*, **24**

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Esposito, L.W., J.R. Winick, A.I.F. Stewart, 1979. *GRL*, **6**, 601.

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Appendix A

Publications for NAG5-1913

Abstracts

Na. C.Y.. Barker. E.S. and S.A. Stern. 1993. Observations of Venus SO_2 in 1993, *BAAS*, **24.**

Na. C.Y.. E. S. Barker. S. A. Stern, and L. W. Esposito. 1993. SO_2 on Venus: IUE, HST, and Ground-based Measurements, and the Active Volcanism Connection. *Lunar and Planetary Science XXIV.*

Festou. M.C.. Stern. S.A.. and Na. C.Y., 1993, Near UV observations of 4179 Toutatis, *ACM meeting proceedings.*

Na. C.Y., S.A. Stern. Buratti B.. and Roettger E. 1994. IUE observation of Iapetus *BAAS.*

Articles

Na, C.Y., Barker, E.S. and S.A. Stern, 1994. Observations of Venus SO_2 in 1993: Comparison between ground-based and IUE observations. *Icarus*, in preparation.

Festou. M.C., Stern. S.A.. and Na. C.Y., 1994, Near UV observations of 4179 Toutatis, *Icarus*, in preparation.

Na. C.Y., S.A. Stern, Buratti B., and Roettger E. 1994. IUE observations of Iapetus: Comparison with asteroids. *GRL*, in preparation.

NEAR-UV OBSERVATIONS OF 4179 TOUTATIS

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Abstract: We observed the fast moving asteroid 4179 Toutatis using the International Ultraviolet Explorer (IUE) spacecraft at the time of its closest approach to the Earth on 10-11 December 1992 ($\Delta = 0.28$–0.32 AU). Four long wavelength ($\lambda\lambda \sim 2400$–3300 Å) UV spectra were obtained that allow the determination of the albedo and the UV color of this small, slowly rotating object. The middle of the first and last spectra were exposed 22 hours apart, thus allowing a limited study of the UV rotational variation of 4179 Toutatis' lightcurve. The IUE data permit us to extend the spectrum of this unusually well observed asteroid significantly below the atmospheric cut-off. Additionally, these data permit comparison of the spectral properties of Toutatis with those of asteroids previously observed with the IUE spectrographs, in particular the large asteroid 4 Vesta.

Observations of Venus SO_2 in 1993

C. Y. Na, (SwRI), E. S. Barker (McDonald Obs./UT Austin),
S. A. Stern (SwRI)

Recent IUE observations of Venus made during greatest elongations in January and June 1993 are presented. We obtained a total of 10 exposures ranging from 0.5 sec to 20 minutes using the LWP camera during 9-12 January 1993. During 8-11 June 1993, a total of 8 additional exposures were obtained using both the large and small apertures of the IUE telescope. A preliminary analysis of the January 1993 observations indicates that the amount of sulfur dioxide at the cloud tops of Venus is around ~50 ppb, and the scale height at the same altitude is ~3 km. These values are similar to the results from previous IUE observations made in 1987 and 1988 [Na et al. 1990], thus indicating that there have been no recent changes in SO_2 abundance above the clouds of Venus.
On the same days as for the IUE observations in January and June 1993, we obtained ground-based, spatially-resolved spectra and images of Venus in the 3000 to 3650 Å region. These spectra will also be used to estimate the SO_2 abundance, and a comparison between the ground-based measurements and the IUE observations will be presented.

SO_2 ON VENUS: IUE, HST AND GROUND-BASED MEASUREMENTS, AND THE ACTIVE VOLCANISM CONNECTION:

C. Y. Na, Southwest Research Institute, E. S. Barker, McDonald Obs. UT Austin, S. A. Stern, Southwest Research Institute, L. W. Esposito, LASP, U. of Colorado, Boulder.

I. SO_2 and volcanism on Venus

UV observations by Pioneer Venus from 1978 to 1986 detected a large decline of SO_2 above the clouds of Venus [1]. The decline of SO_2 has been confirmed by the International Ultraviolet Explorer (IUE) observations made in 1979 and 1987 [2]. Pioneer Venus also observed a decline in sulfuric acid aerosols from the polar regions of Venus [3]. Further still, both Pioneer Venus and Galileo have detected radio signals that have been attributed to lightning activities in the atmosphere of Venus [4,5]. Based on these observations, Esposito [6] proposed that the Venus may be volcanically active, and the large decline of SO_2 above the clouds can be interpreted as the recovery of the atmosphere following the injection of SO_2 from a volcanic eruption. If this hypothesis is correct then remote sensing of the Venus atmosphere may provide important clues to the current state of Venus geology.

In early November 1991, we obtained IUE spectra of Venus with the Long Wavelength Prime (LWP) spectrograph. On the same days, we obtained spatially resolved spectra and images of Venus using the 2.7m telescope at McDonald observatory [7]. As shown in the accompanying figure, these two observations seem to indicate that the mixing ratio of SO_2 above the cloud increased by about a factor of 2 since 1990.

More coordinated IUE and ground-based observations are planned for 1993 to determine whether the increase of SO_2 has continued. The first of the planned observation is to take place using IUE and the 2.7m telescope at McDonald observatory from 8 January to 12 January. The results from these new observations will be presented. At the time of Venus' western elongation in early June 1993, we hope to obtain (i) IUE spectra, (ii) ground-based spectra, and (iii) the first-ever Hubble Space Telescope (HST) spectra of Venus. If SO_2 is indeed increasing above the clouds, then these measurements may help us to determine the rate of increase in SO_2 above the clouds.

II. SO, S_2O and dark markings

IUE observations of Venus were used to identify SO (sulfur monoxide) in the atmosphere Venus for the first time [2]. According to photochemical models [8], SO plays an important role in the chemical processes in the upper clouds. The mixing ratio of SO was determined from IUE and rocket observations to be about 10% of SO_2 [9]. The disulfur monoxide, S_2O, which is produced from photochemical reactions involving SO may be responsible for the dark markings in the clouds [10]. Thus the IUE observations of Venus are not only important in documenting the long-term change in SO_2 and SO, but are also important in understanding the chemistry and dynamics of the Venus atmosphere.

HST observations of Venus are critical because, with the end of the Pioneer Venus mission, HST will be only instrument capable of making regular observations beyond IUE which is starting its 16th year in orbit. HST can both make images and take spectral observations. The imaging capability of HST will make a valuable contribution to understanding the connection between the atmospheric dynamics and the distribution of photochemically active species.

III. Conclusion

Magellan images have shown that the volcanic features are widespread over the surface of Venus. The question of whether there is active volcanism is important for understanding both the atmospheric and the geological processes on Venus. The thick cloud cover of Venus precludes any direct observation of active volcanoes even if they exist. The only means of monitoring the active volcanism on Venus at present seems to be remote sensing from Earth. Continuous of monitoring of SO_2 is important to establish the long term trend of SO_2 abundance and to understand the physical mechanism responsible for the change.

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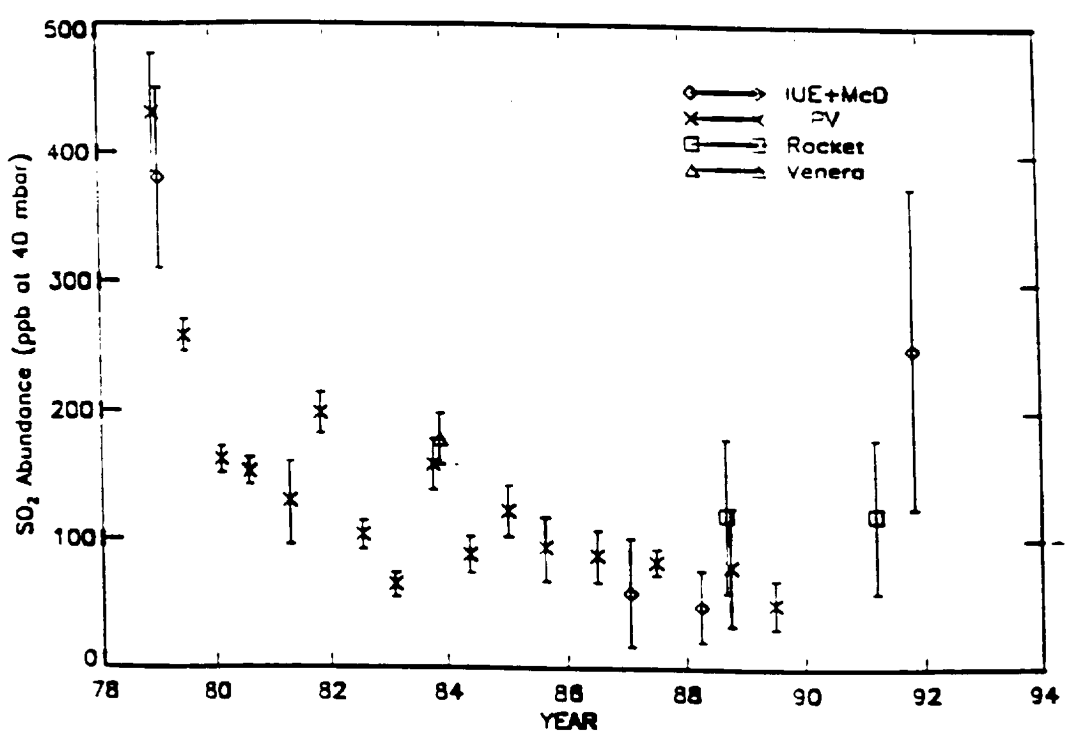
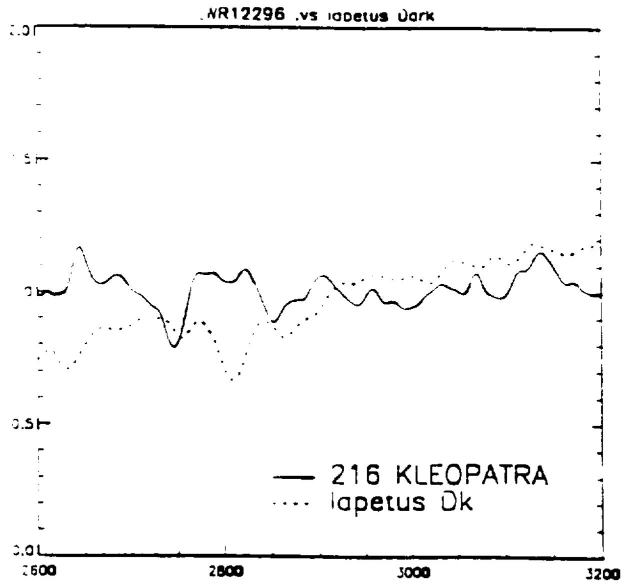


Mixing ratio of SO_2 at the cloud top level in the Venus atmosphere derived from the IUE, rocket, Pioneer Venus, Venera-15, and ground-based observations.

Appendix B

Comparison of Iapetus with asteroids.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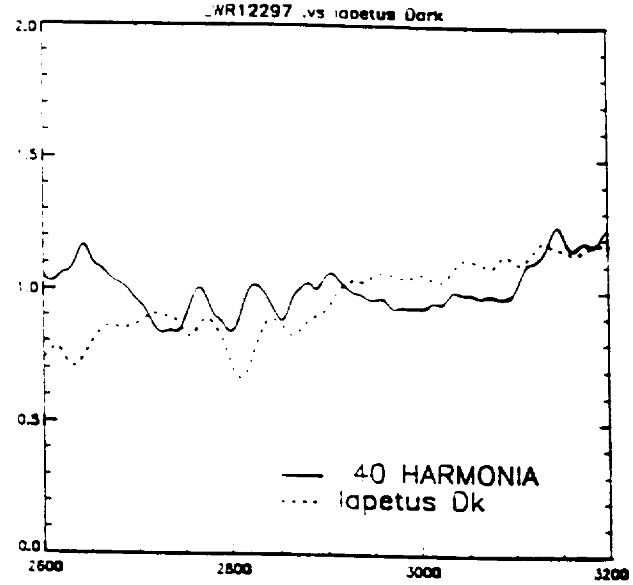
2600
2800
3000
3200
216 KLEOPATRA
Iapetus Dk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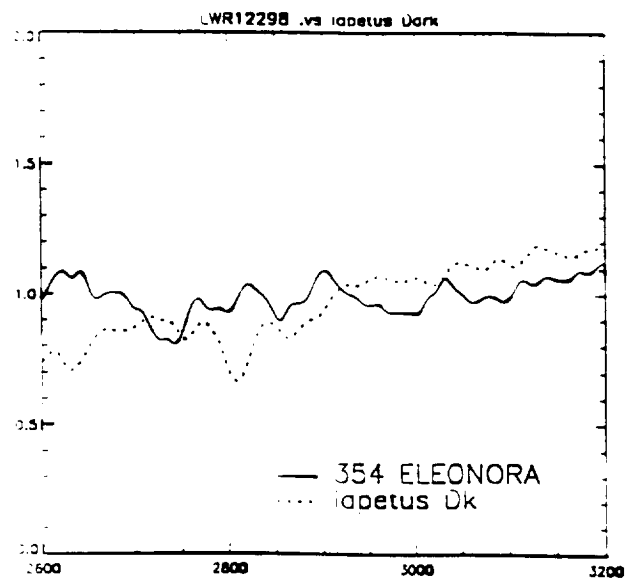
40 HARMONIA
Iapetus Dk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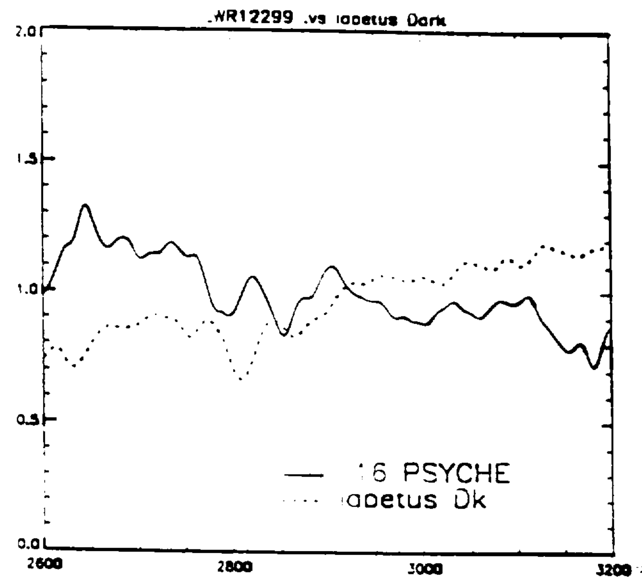
Iapetus Dk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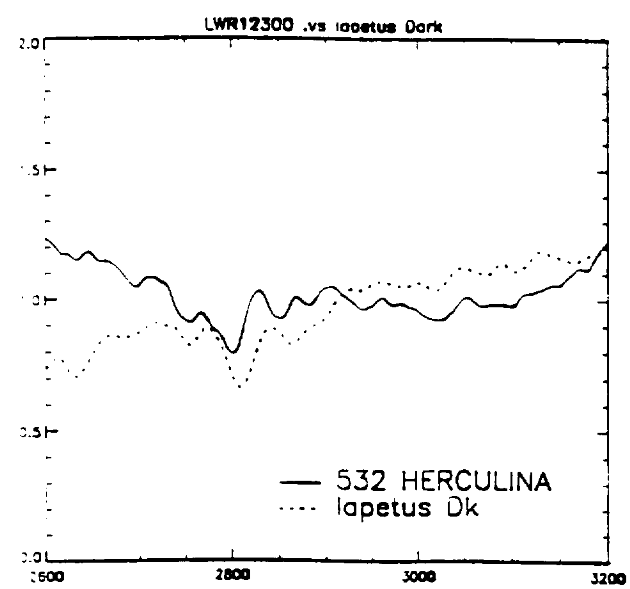
3000
3200
PSYCHE
Iapetus Dk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0.5
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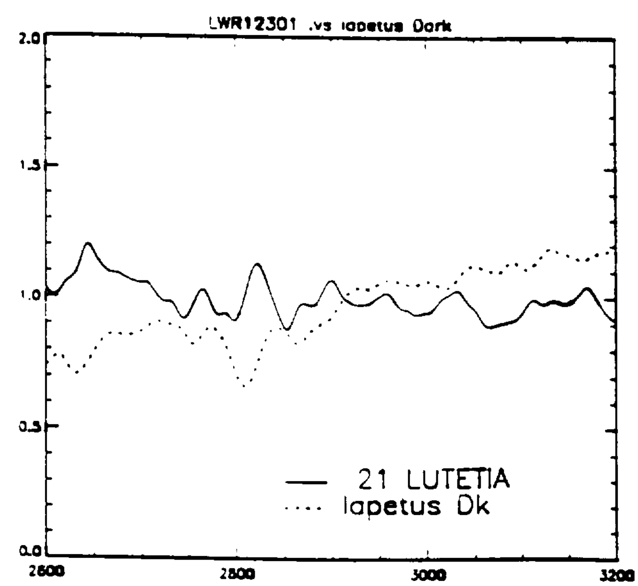
2800
3000
3200
532 HERCULINA
Iapetus Dk


LWR12301 .vs Iapetus Dark
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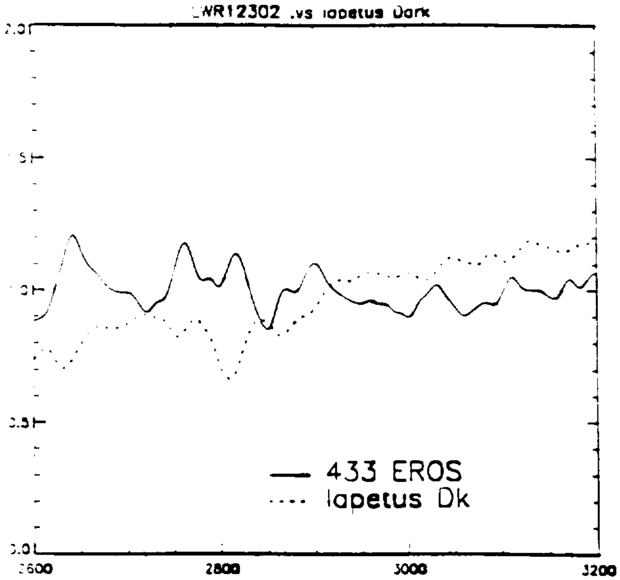
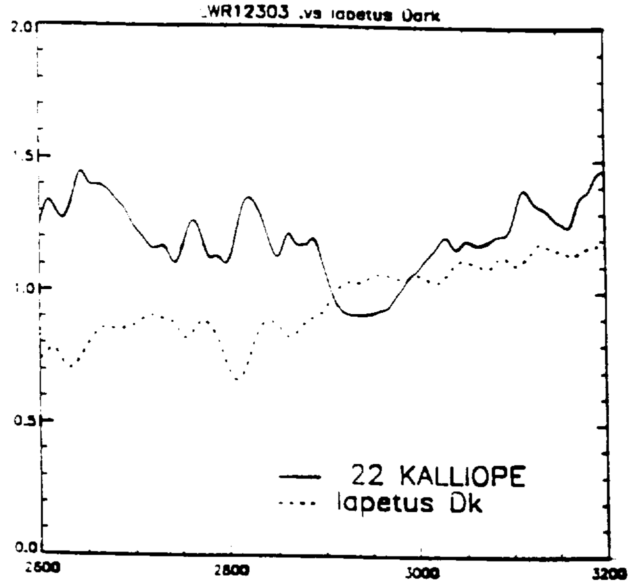
1.5
1.0
0.5
0.0
2600
2800
3000
3200
21 LUTETIA
Iapetus Dk

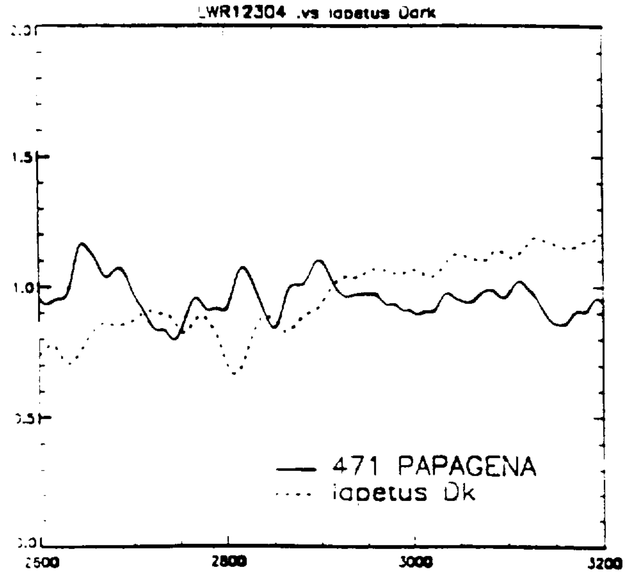
LWR12302 .vs Iapetus Dark



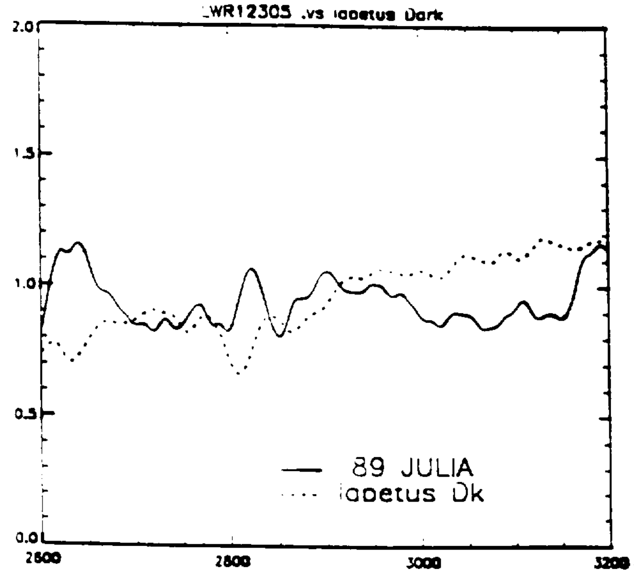
LWR12303 .vs Iapetus Dark



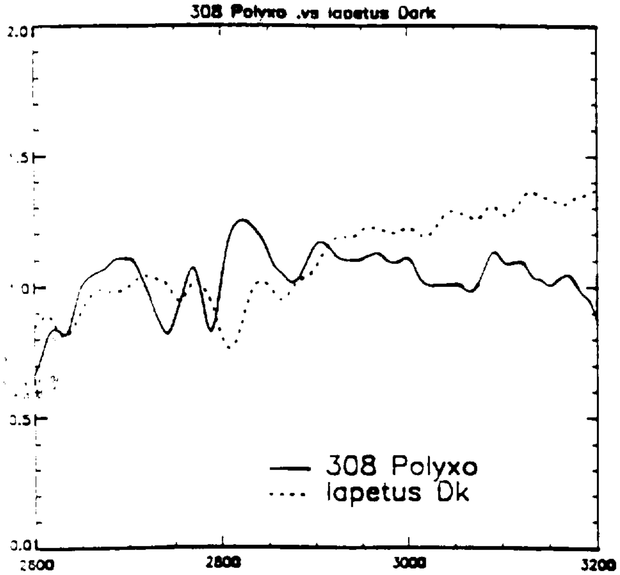
LWR12304 .vs Iapetus Dark



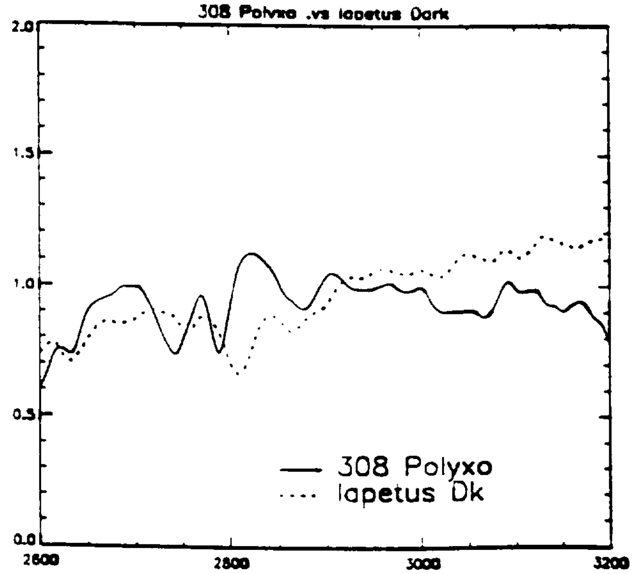
LWR12305 .vs Iapetus Dark



308 Polyxo .vs Iapetus Dark



308 Polyxo .vs Iapetus Dark



Appendix C

IUE observation of Venus SO_2 in 1993.

SO_2 on Venus in 1993:
IUE and Ground-Based Observations

C. Y. Na, (Southwest Research Institute), E. S. Barker, (McDonald Obs. UT Austin), S. A. Stern, (Southwest Research Institute)

Abstract

We present the results from IUE observations of Venus SO_2 made in January 9-12, 1993. We obtained a total of 10 spectra using LWP camera in both high and low dispersion mode. Analysis of these spectra indicates that the abundance of SO_2 in 1993 is about 75 ± 30 ppb above the clouds, and that the scale height at 40 mbar level is around 3 km. We have reported that there may have been a slight increase of SO_2 above the clouds of Venus based on ground-based observations along with IUE in November of 1991. Our most recent observations, however, preclude any recent large scale increase of SO_2 above the clouds of Venus

Introduction

UV observations by Pioneer Venus from 1978 to 1986 detected a large decline of SO_2 above the clouds of Venus [1]. The decline of SO_2 has been confirmed by the International Ultraviolet Explorer (IUE) observations made in 1979 and 1987 [2]. Pioneer Venus also observed a decline in sulfuric acid aerosols from the polar regions of Venus [3]. Further still, both Pioneer Venus and Galileo have detected radio signals that have been attributed to lightning activities in the atmosphere of Venus [4,5]. Based on these observations, Esposito [6] proposed that the Venus may be volcanically active, and the large decline of SO_2 above the clouds can be interpreted as the recovery of the atmosphere following the injection of SO_2 from a volcanic eruption. If this hypothesis is correct then remote sensing of the Venus atmosphere may provide important clues to the current state of Venus geology.

Magellan images have shown that the volcanic features are widespread over the surface of Venus. The question of whether there is active volcanism is important for understanding both the atmospheric and the geological processes on Venus. . Continuous of monitoring of SO_2 is important to establish the long term trend of SO_2 abundance and to understand the physical mechanism responsible for the change.

References

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[4] Kansformality, L. (1980), *Nature*, 284, 244

[5] Gurnett, D. A. et al. (1991), *Science*, 253, 1522

[6] Esposito L. W. (1984), *Science*, 223, 1072

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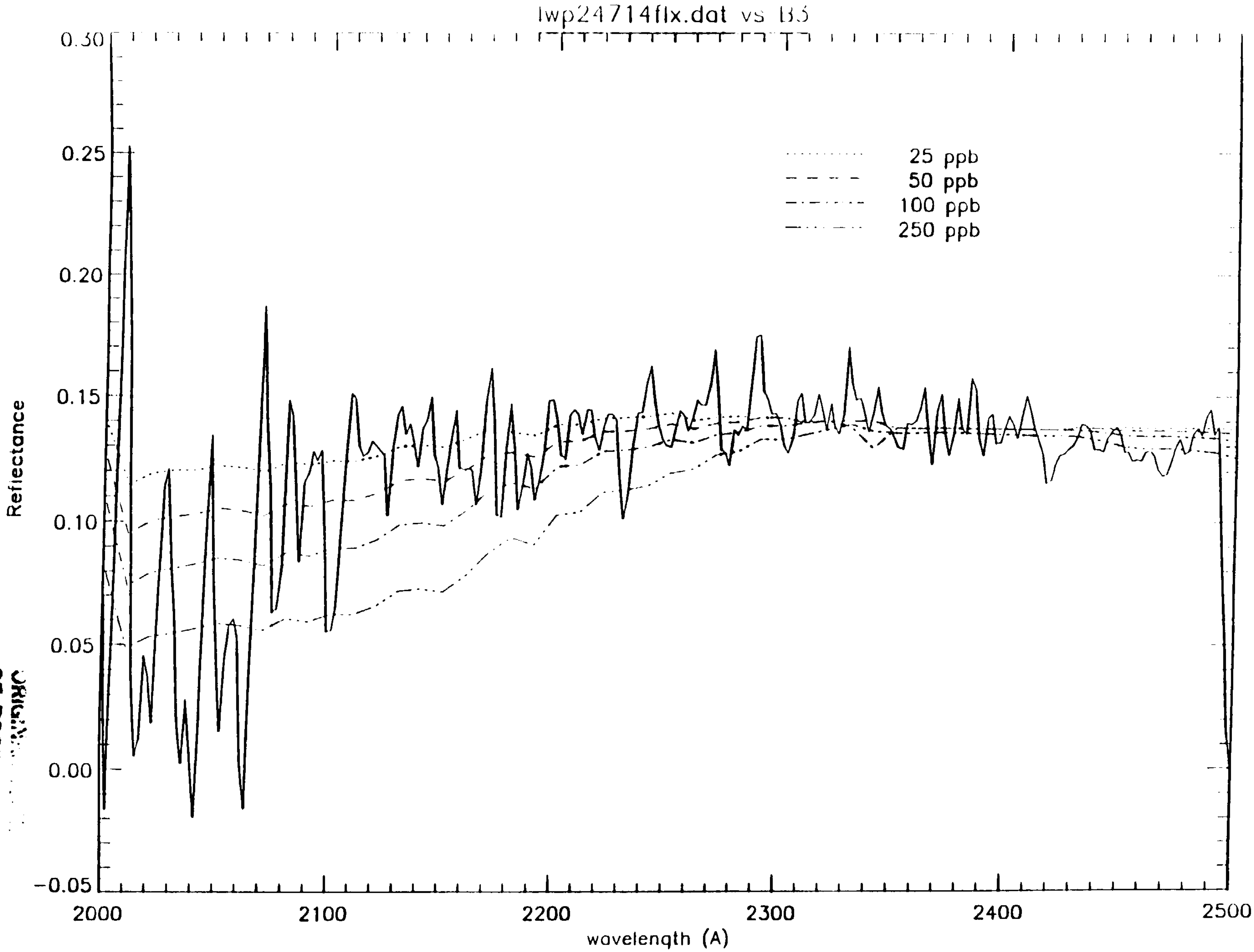
Observations

In early November 1991, we obtained IUE spectra of Venus with the Long Wavelength Prime (LWP) spectrograph. On the same days, we obtained spatially resolved spectra and images of Venus using the 2.7m telescope at McDonald observatory [7]. As shown in the accompanying figure, these two observations seem to indicate that the mixing ratio of SO_2 above the cloud increased by about a factor of 2 since 1990. More coordinated IUE and ground-based observations were carried out in January and June of 1993 to determine whether the increase of SO_2 has continued. The first of the planned observation took place using IUE and the 2.7m telescope at McDonald observatory from 8 January to 12 January. The results from these new observations are presented.

Date	Camera	Image No.	Dispersion	Aperture
1/9/93	LWP	24696	Low	Large
1/9/93	LWP	24697	High	Small
1/9/93	LWP	24698	High	Small
1/10/93	LWP	24702	High	Small
1/10/93	LWP	24703	High	Small
1/10/93	LWP	24704	High	Small
1/11/93	LWP	24714	Low	Large
1/11/93	LWP	24715	High	Large
1/11/93	LWP	24716	High	Small
1/12/93	LWP	24727	High	Small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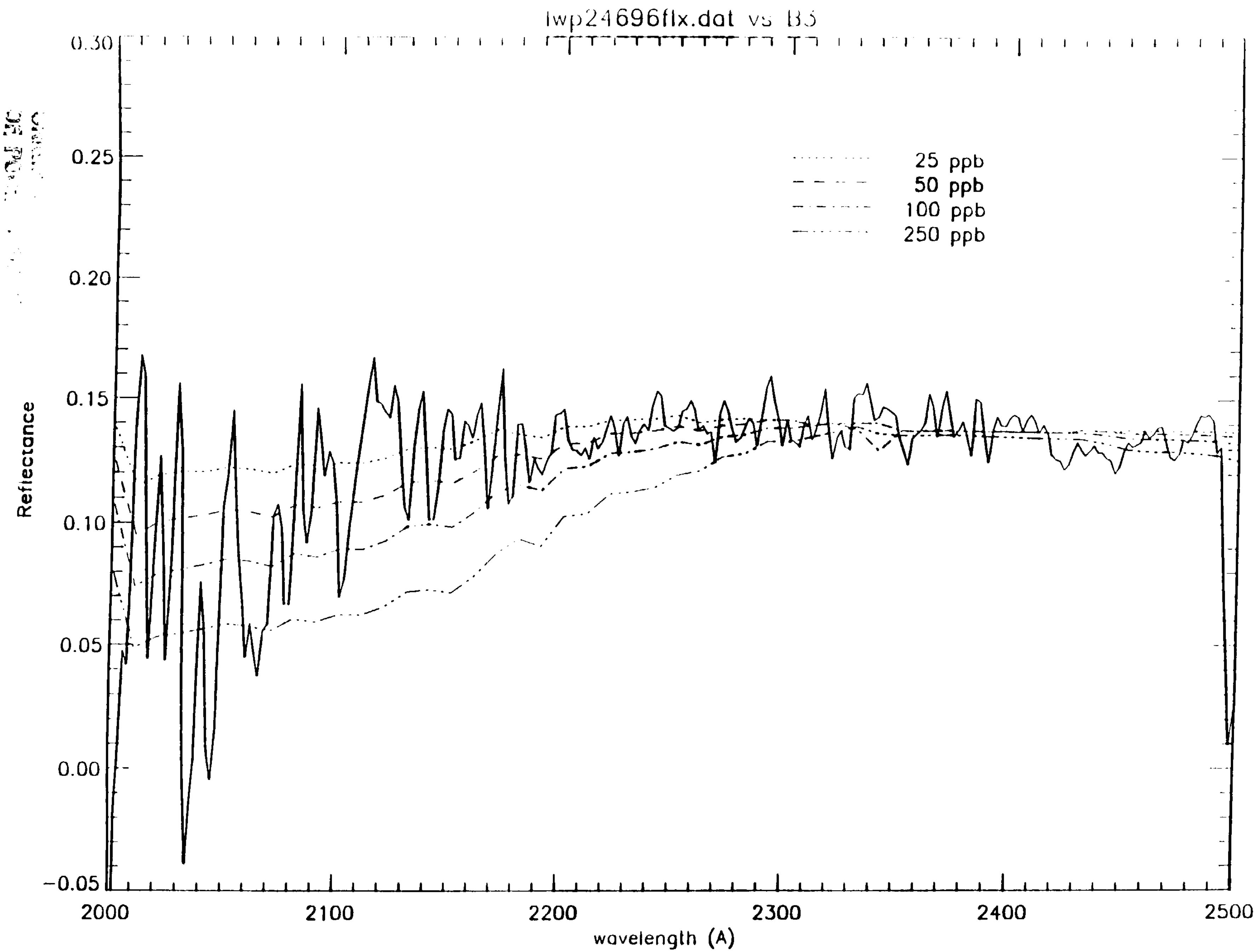
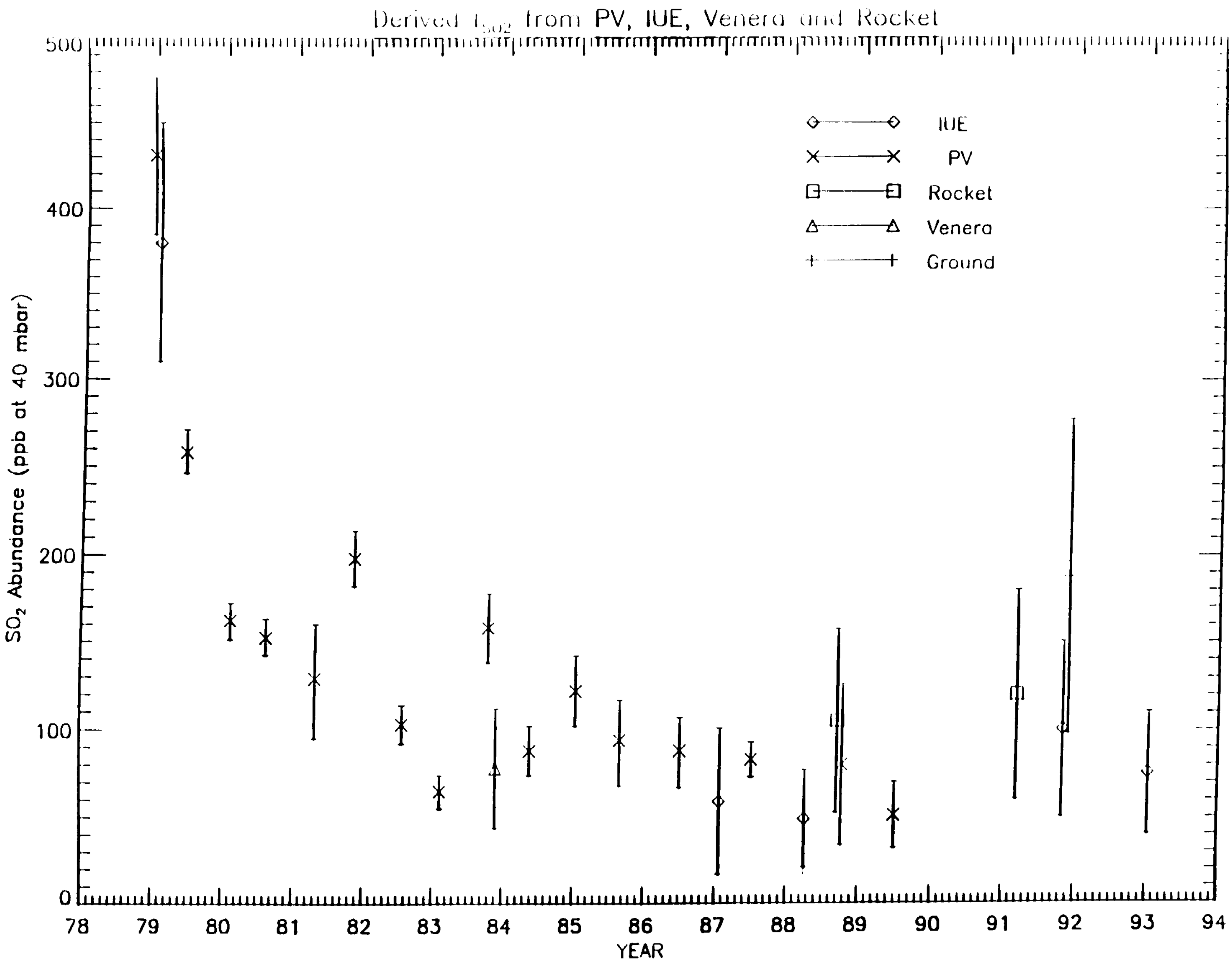
50 ppb
100 ppb
250 ppb
Reflectance
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
2000
2100
2200
2300
2400
2500
wavelength (A)


lwp24696flx.dat vs B5
25 ppb
50 ppb
100 ppb
250 ppb
Reflectance
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
2000
2100
2200
2300
2400
2500
wavelength (A)



Derived f_{SO_2} from PV, IUE, Venera and Rocket
IUE
PV
Rocket
Venera
Ground
SO_2 Abundance (ppb at 40 mbar)
500
400
300
200
100
0
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
YEAR